Nuclear and Atomic Physics

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Both nuclear and atomic physics are of course vast subjects, and the research done at NIC supercomputers can cover only some narrow aspects. Indeed there were four major projects in this field, all dealing with fundamental questions. All four dealt with few-body problems and had some connections to particle physics.

Two projects were concerned with few-nucleon systems, i.e. with the structures and dynamics of the lightest nuclei, with $A = 3$ to 12. The challenge here is that neither the precise basic interaction nor any exact scheme to solve the equations of motion are known. Thus any theory must check carefully whether discrepancies with experiment are due to numerical difficulties or due to imperfections in the interaction ansatz. One main problem here is that 3-nucleon forces are known to be present, mainly because of relativistic and other degrees of freedom (e.g. baryon resonances) which cannot be treated explicitly in a non-relativistic Schrödinger equation. Moreover, while the Schrödinger equation for three nucleons can still be solved numerically with high precision, this is no longer true for more than three nucleons.

In the only paper on these problems included in this volume, W. Glöckle and colleagues discuss mainly three-baryon systems from this point of view. In addition to the "classic" problem of scattering in three-nucleon systems, where a whealth of precise experimental results is available, they also discuss hypernuclei and scattering processes involving photons. This paper shows impressively how high-performance computing has led to important recent progresses, but points also to difficulties which will keep researchers busy for the next few years.

The other big project on the nuclear few-body problem at NIC, by H.M. Hofmann *et al.* from Erlangen University, deals with somewhat larger nuclei. There, a straightforward solution of the Schrödinger equation is impossible, and one has to resort to variational methods. In particular, these authors use the *Refined Resonating Group Model* where the wave function is decomposed into a set of Gaussians. They use a genetic algorithm for optimizing the parameters of this set. If, in addition, realistic forces are used (including three-nucleon forces), one arrives again at a problem where high-performance supercomputing is essential. One reward is then that one finds good agreement with experimental scattering data in four-nucleon systems (e.g., n-t and p-^{3}He scattering).

The two projects on atomic physics (by J. Eichler *et al.* from the Hahn-Meitner-Institute in Berlin, and by W. Scheid *et al.* from Gießen University) both are concerned with electron-positron pair production in relativistic heavy-ion collisions. In spite of its deceptive simplicity, this has been a fascinating problem ever since it was demonstrated experimentally nearly ten years ago. It obviously probes the structure of the vacuum, it cannot be treated perturbatively, and it needs a fully relativistic treatment. The latter is highly non-trivial. Indeed, as shown by Eichler *et al.*, all known numerical schemes violate Lorentz symmetry, and the induced errors are not small. Scheid and colleagues, on the other hand, show that previous perturbative treatments were substantially wrong.

The numerical treatment of pair production in heavy-ion collisions is made feasable since the two nuclei can be assumed to move on straight lines. In spite of this simplification, the problem remains a formidable challenge for high-performance supercomputing. Indeed, the various numerical methods used by both groups are quite different, although all of them finally burn down to the integration of large systems of differential equations.

In summary we see again that high performance supercomputing is essential if one wants to make detailed comparison with experiments, given the inherent complexities of even simple-looking systems. This is not to say that no progress can be made with much less numerical efforts, in particular if the theorist can select the problem he wants to work on. But there will always be problems – and these often are the great challenges – which require computations which can only be done on state of the art supercomputers.